A Near-Field Modulation Technique Using Antenna Reflector Switching

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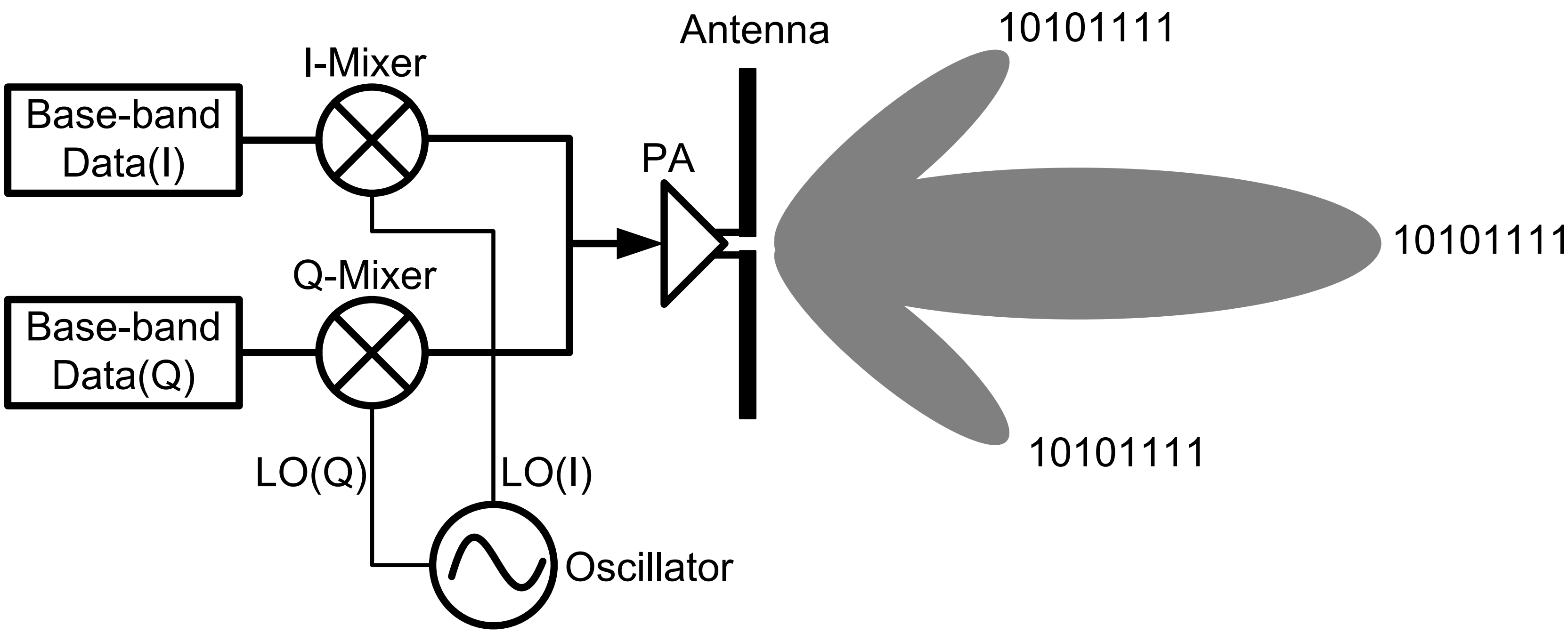
Outline

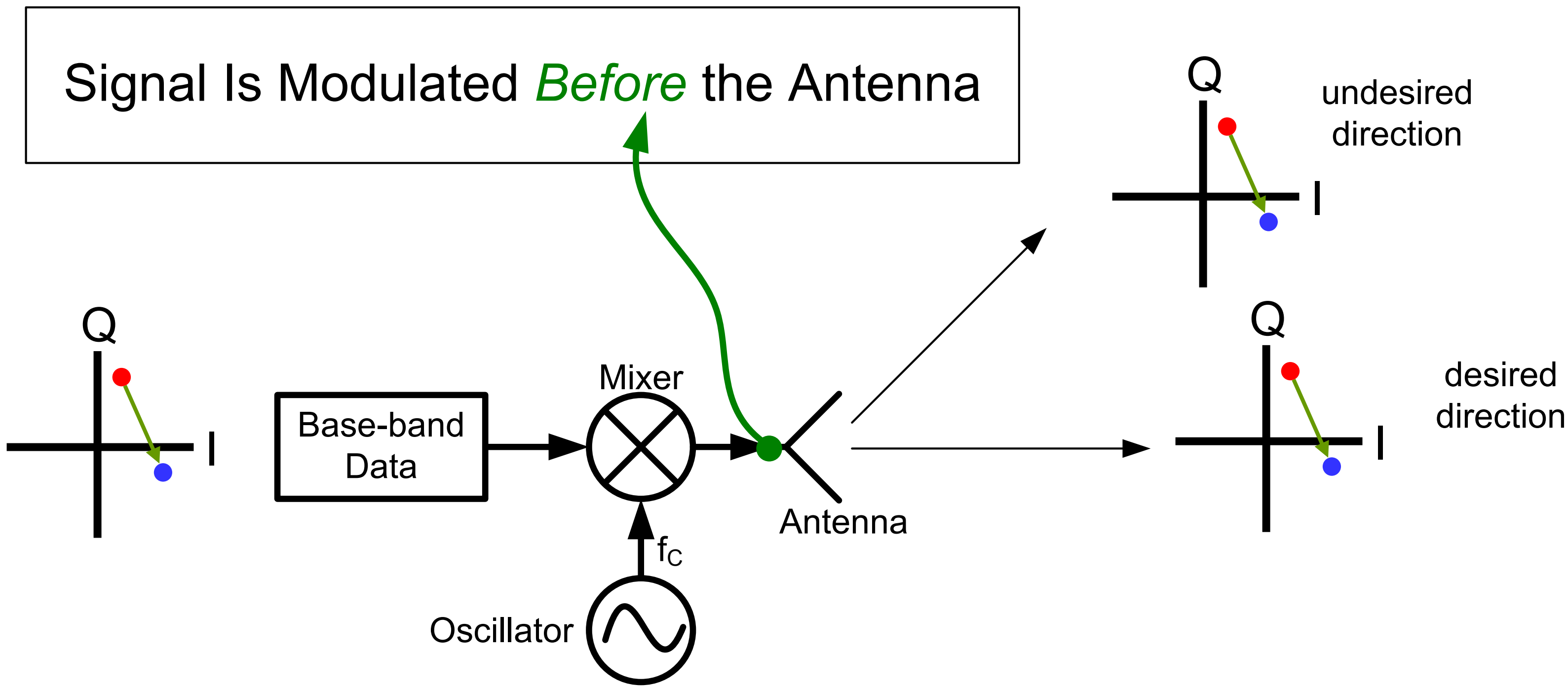
- Introduction
- Signal Modulation using Antenna Reflector Switching (SMARS)
- A 60GHz Proof-of-Concept Transmitter
- Experimental Results
- Conclusion

Conventional Transmitter Architecture



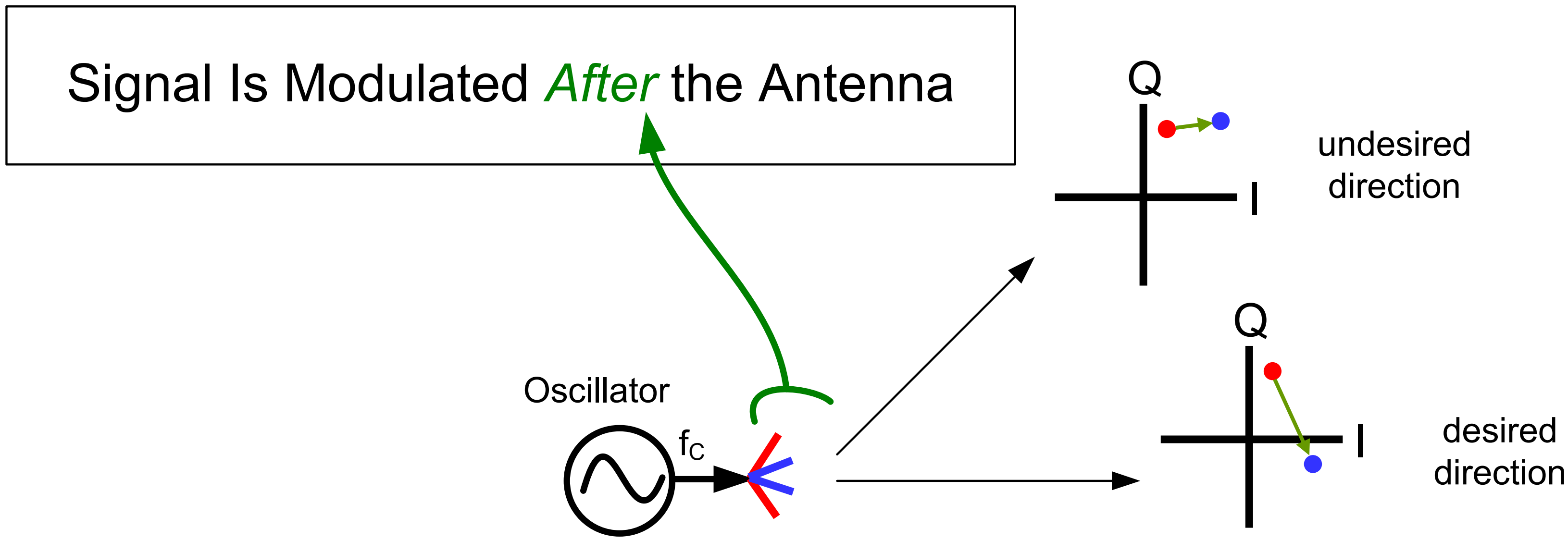
- Signal is modulated at base-band.
- Antenna transmits **the same information** to all directions.
- The only difference between the desired and the undesired directions is the transmitted power level.
- A high-performance receiver at an undesired direction is able to receive and decode the correct modulated signal.

Modulation at the Base-Band



- In the conventional architectures, the antenna pattern remains unchanged at each symbol transmission.
- For a fixed antenna pattern, any change in the phase and the amplitude of the base-band signal is detectable at the desired direction as well as the undesired direction.

Modulation After the Antenna



- In the proposed transmitter architecture, antenna near-field and far-field change at each symbol transmission but the change in the far-field is **not same** for all the angles.
- Antenna pattern needs to be varied **at the same rate as the symbol-rate** to be able to modulate the signal.

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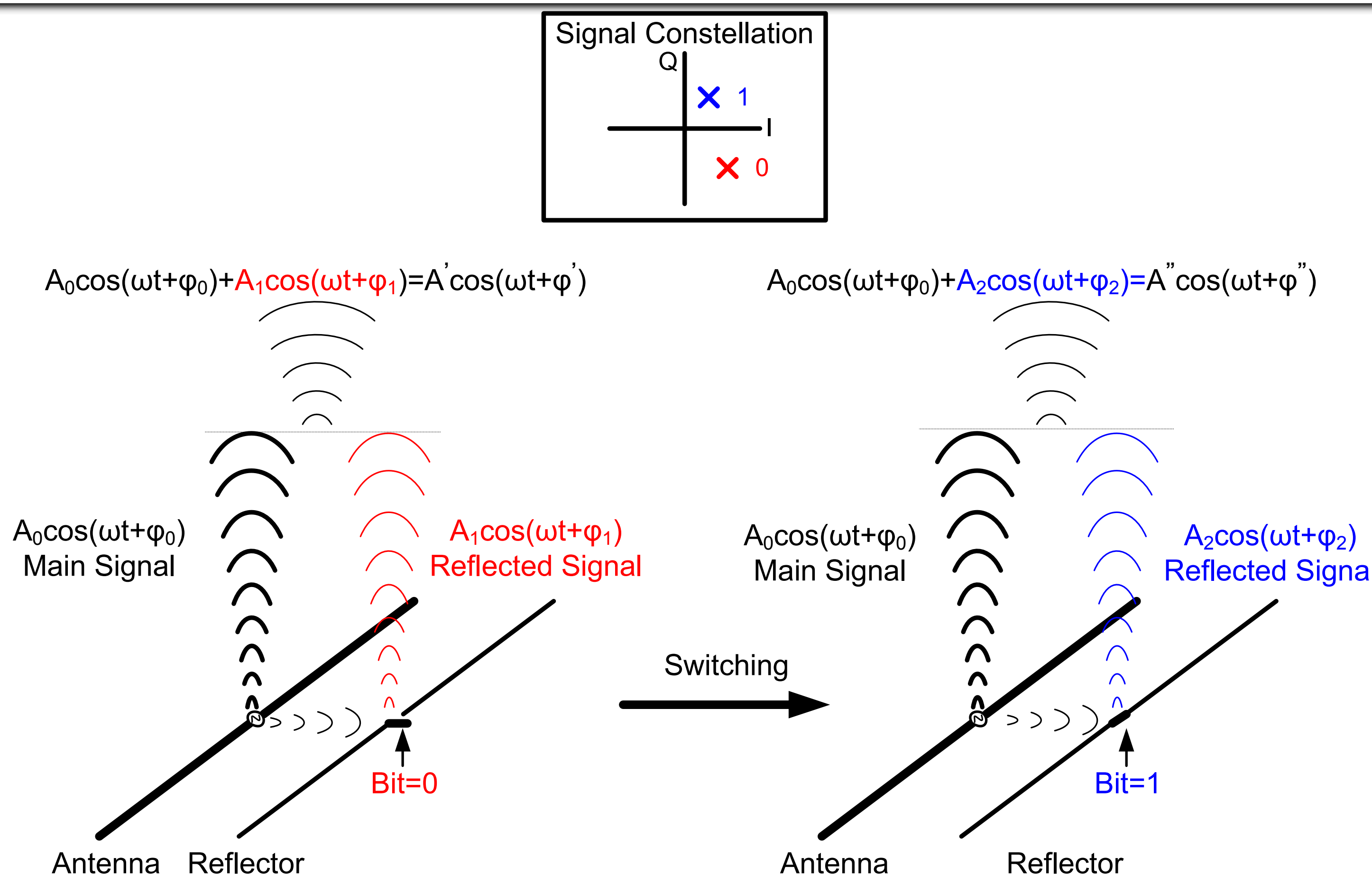
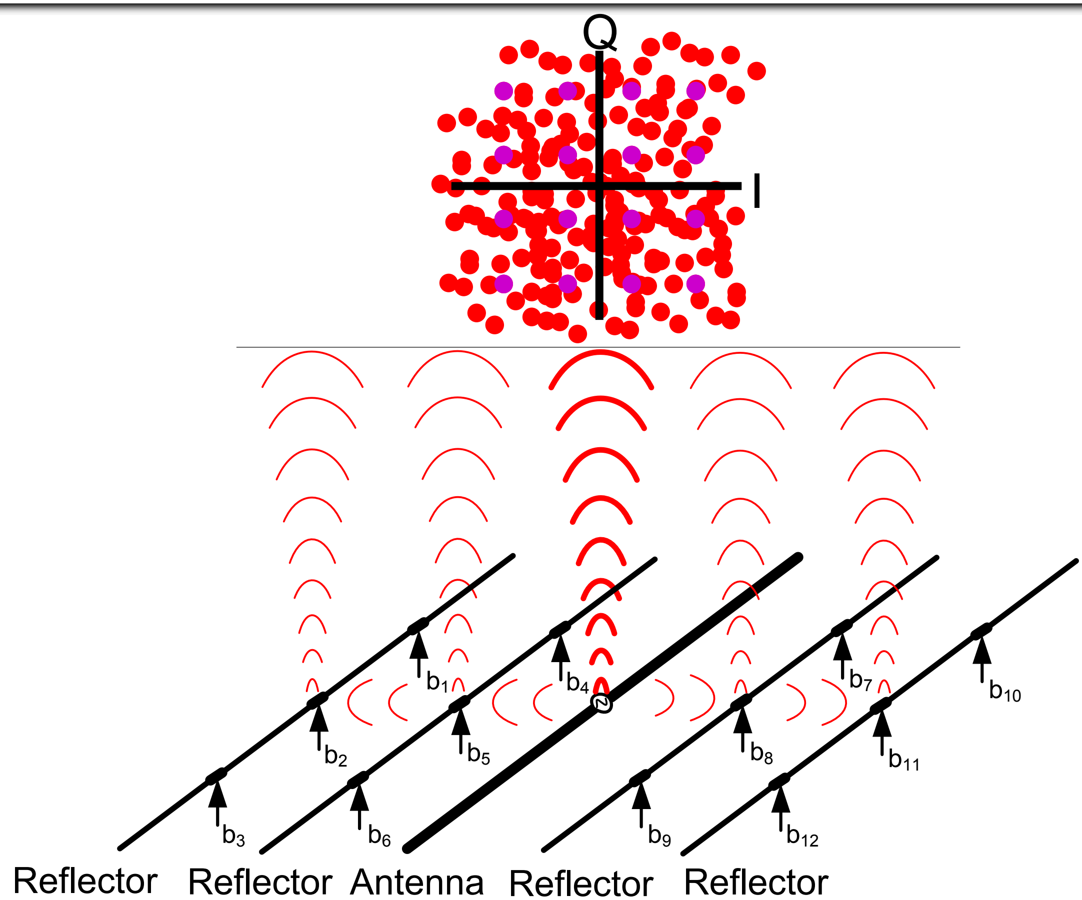
Signal Modulation



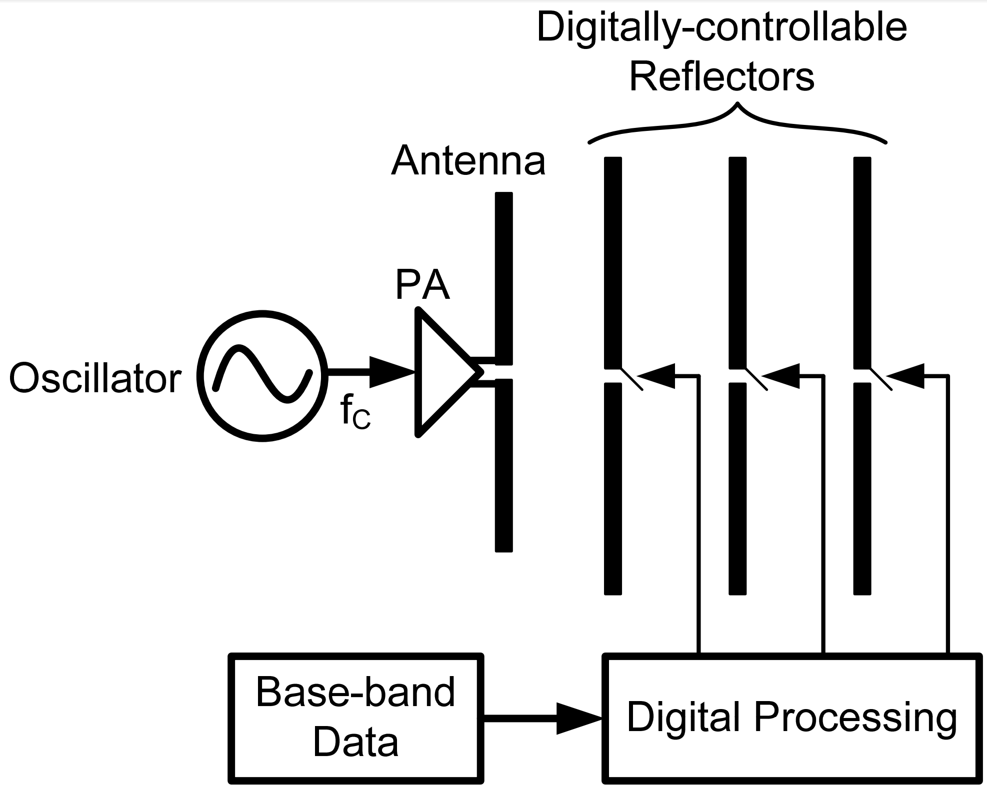
- Switching changes the antenna reflector's effective length.
- Reflected signal interferes with the main signal.
- Different effective lengths correspond to different phases and amplitudes of the reflected signal.

Arbitrary Signal Modulation



- We can generate more constellation points by introducing additional reflectors and switches.
- Each additional switch doubles the total number of possible constellations points.

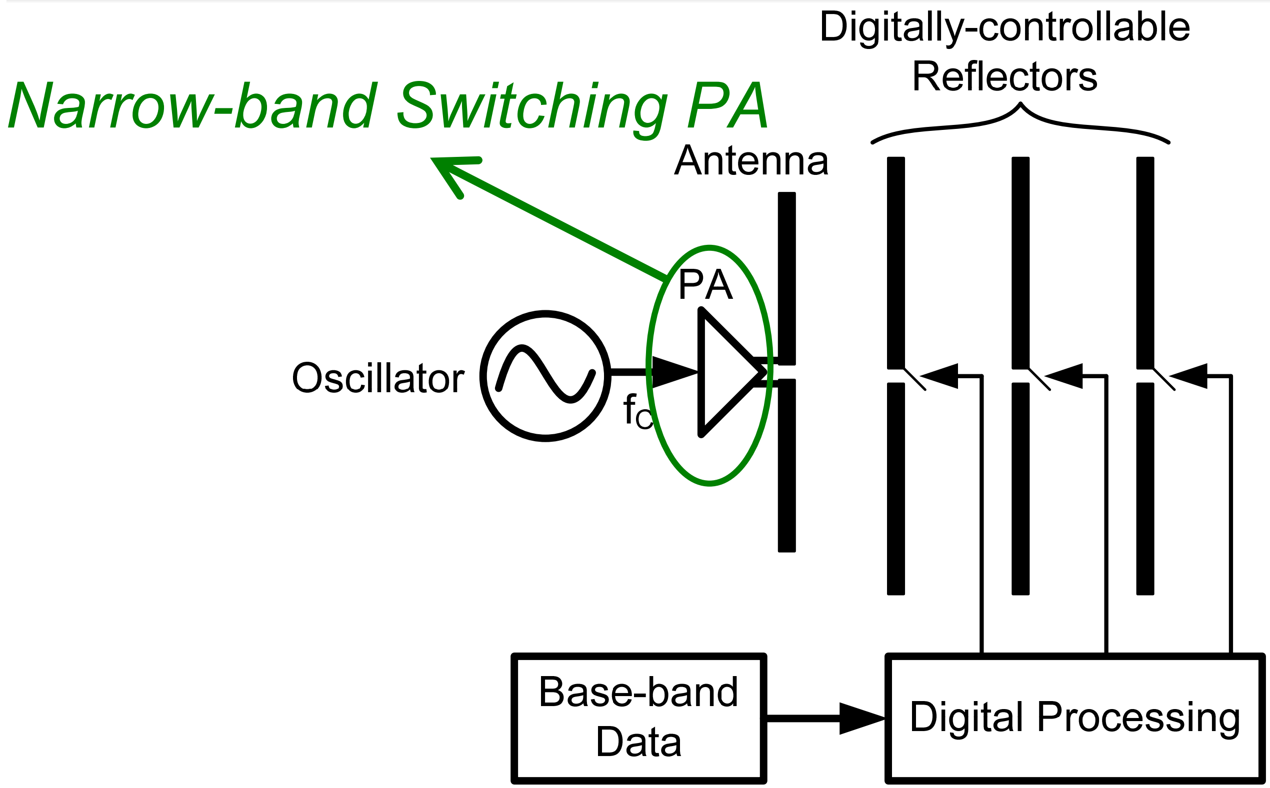
SMARS Transmitter Architecture[1]



- In the SMARS (Signal Modulation using Antenna Reflector Switching) transmitter architecture, **high-speed CMOS switches** are used to modulate the signal.

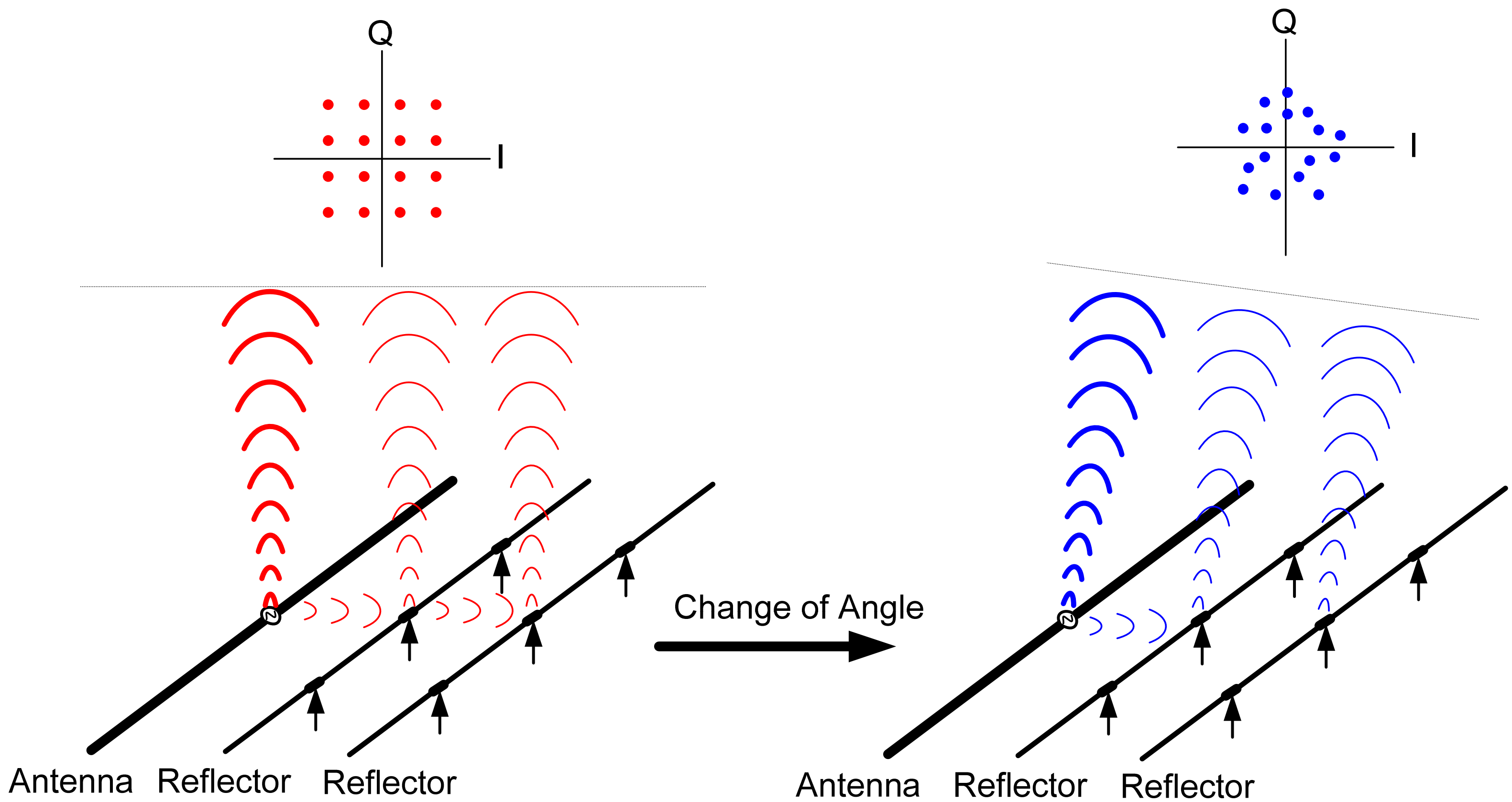
[1]A. Babakhani *et al.,* "*A New Transmitter Architecture based on Antenna Parasitic Switching* ," U.S. Patent Pending

SMARS Transmitter Architecture[1]



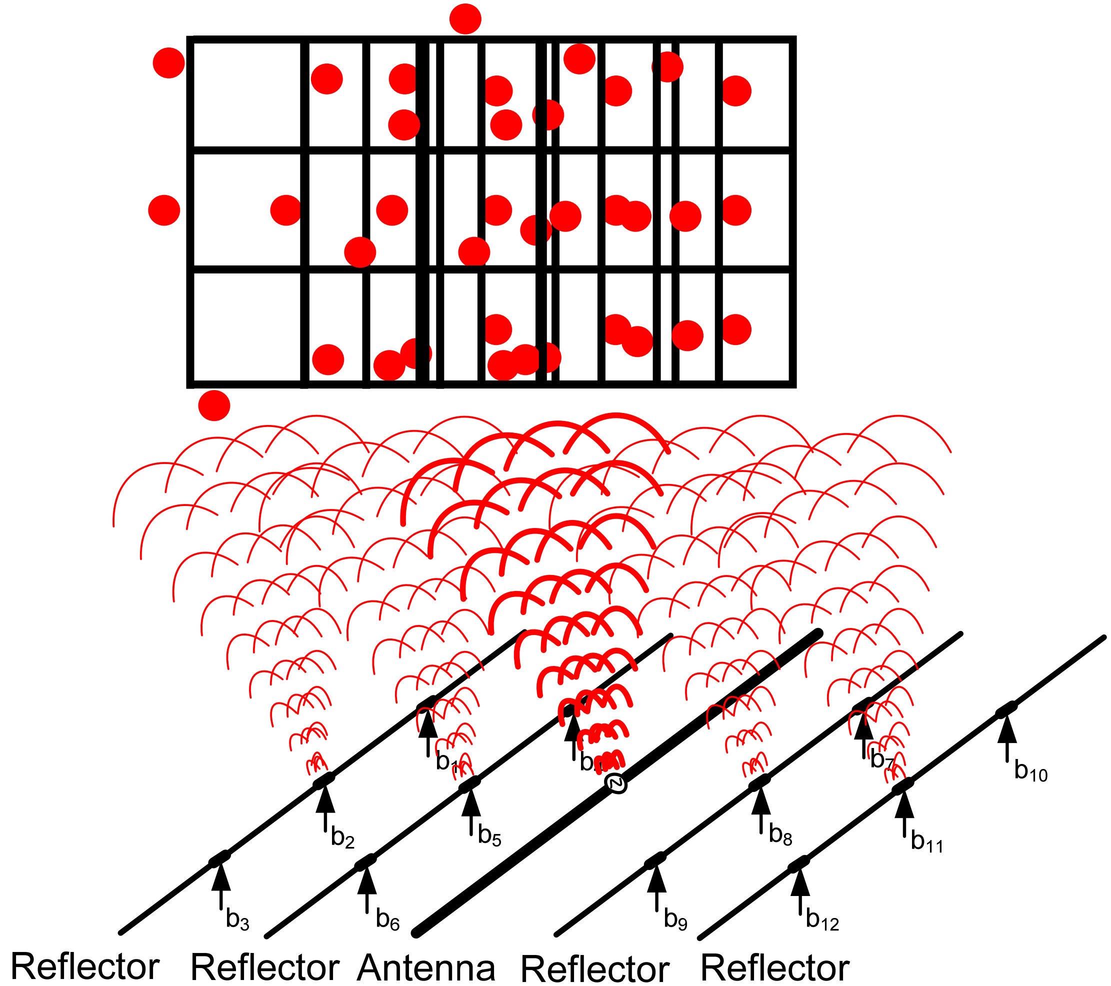
- As the signal is modulated after the antenna, the PA can operate at its maximum efficiency point while transmitting a non-constant envelope modulated signal.
- A **narrow-band** highly efficient **switching PA** can be used to amplify the carrier signal.

Secure Communication Link



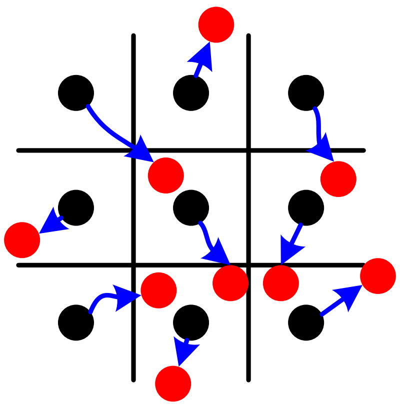
- Angle dependent modulation provides a secure communication link.
- Correctly modulated signal is only transmitted to the desired direction.

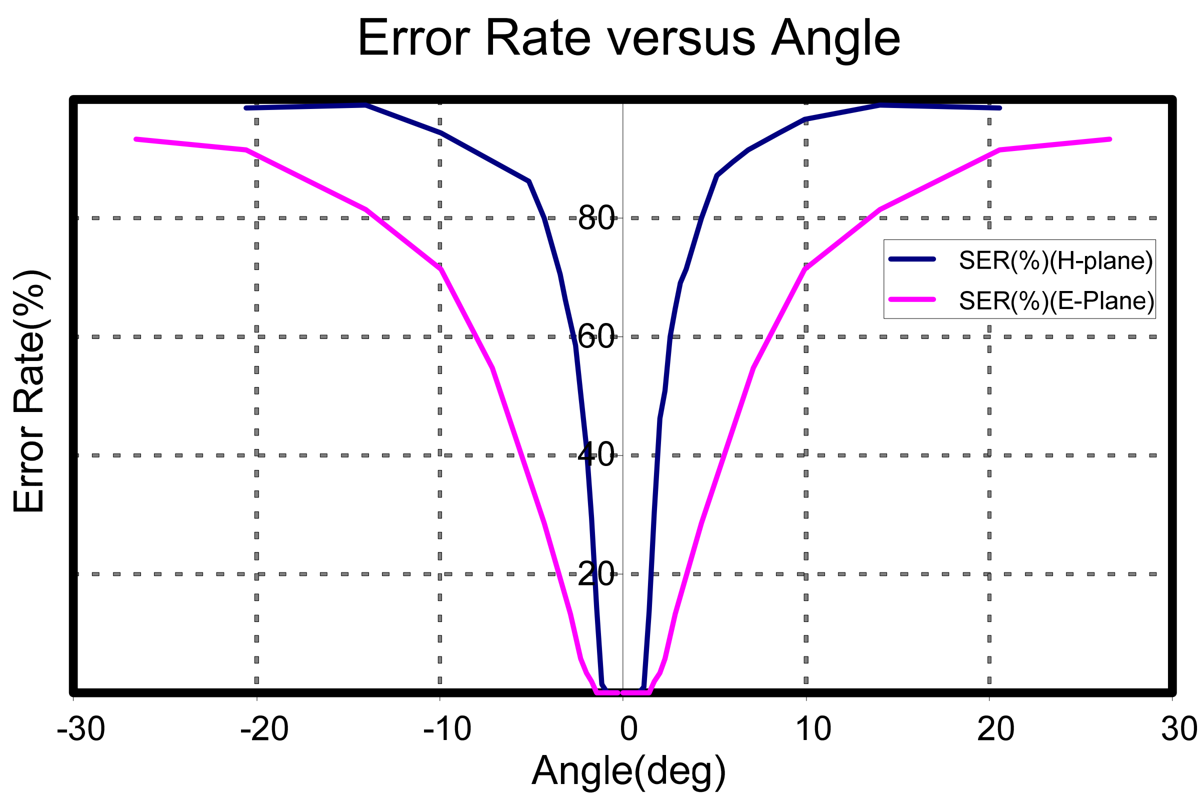
Error-Rate Versus Angle



- By changing the angle, some of the constellation points move to the adjacent cells and introduce error.

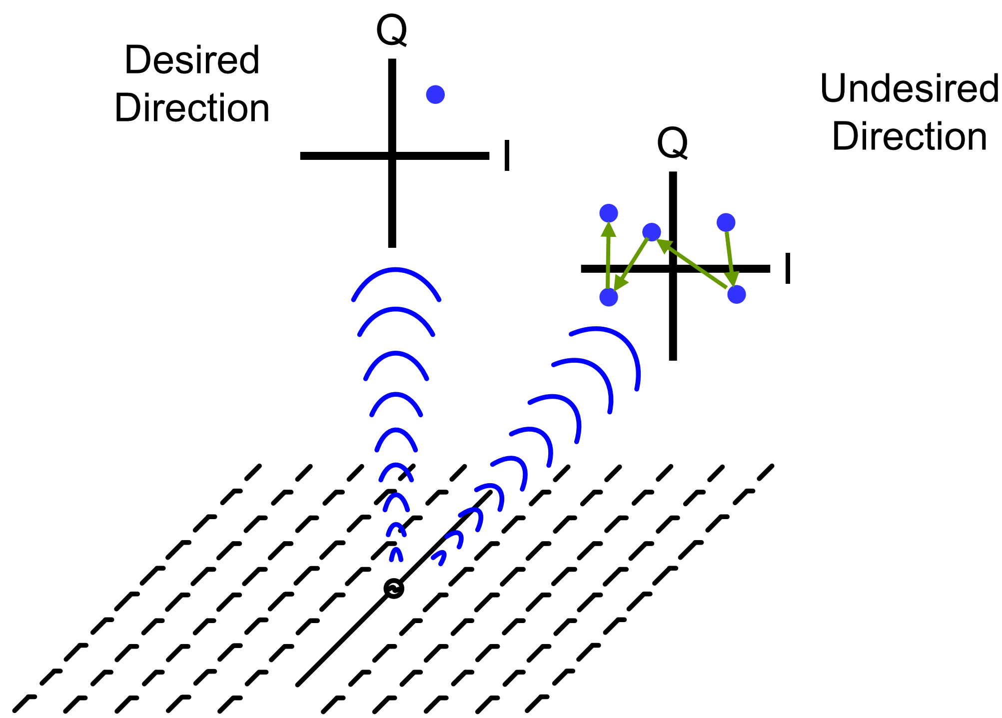
Information Beam-Width





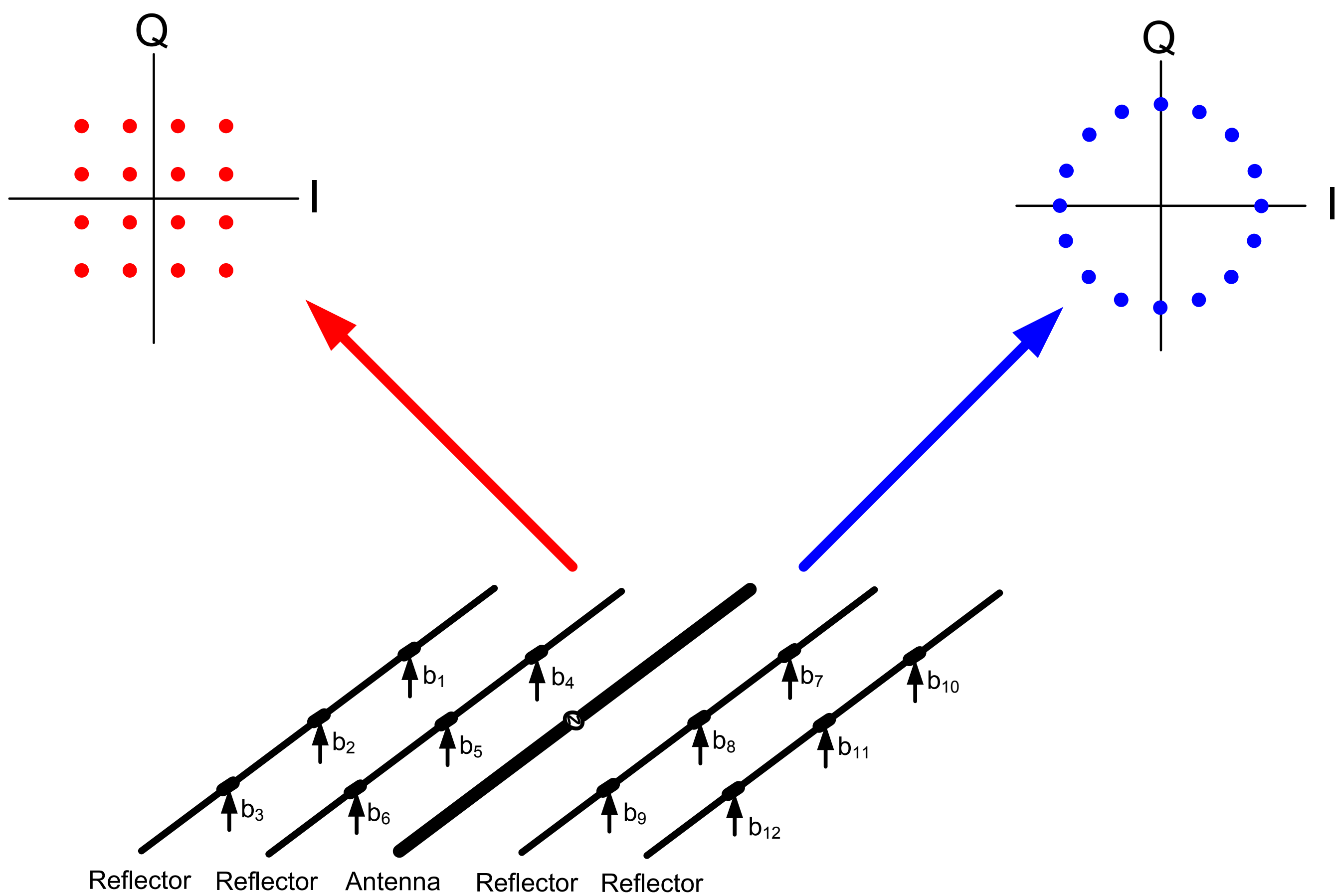
- A total number of 210 equally-spaced points are selected.
- Boresight is set to be the desired direction in this example.
- The desired direction can be steered by finding a set of different switching combinations.

High Level of Redundancy



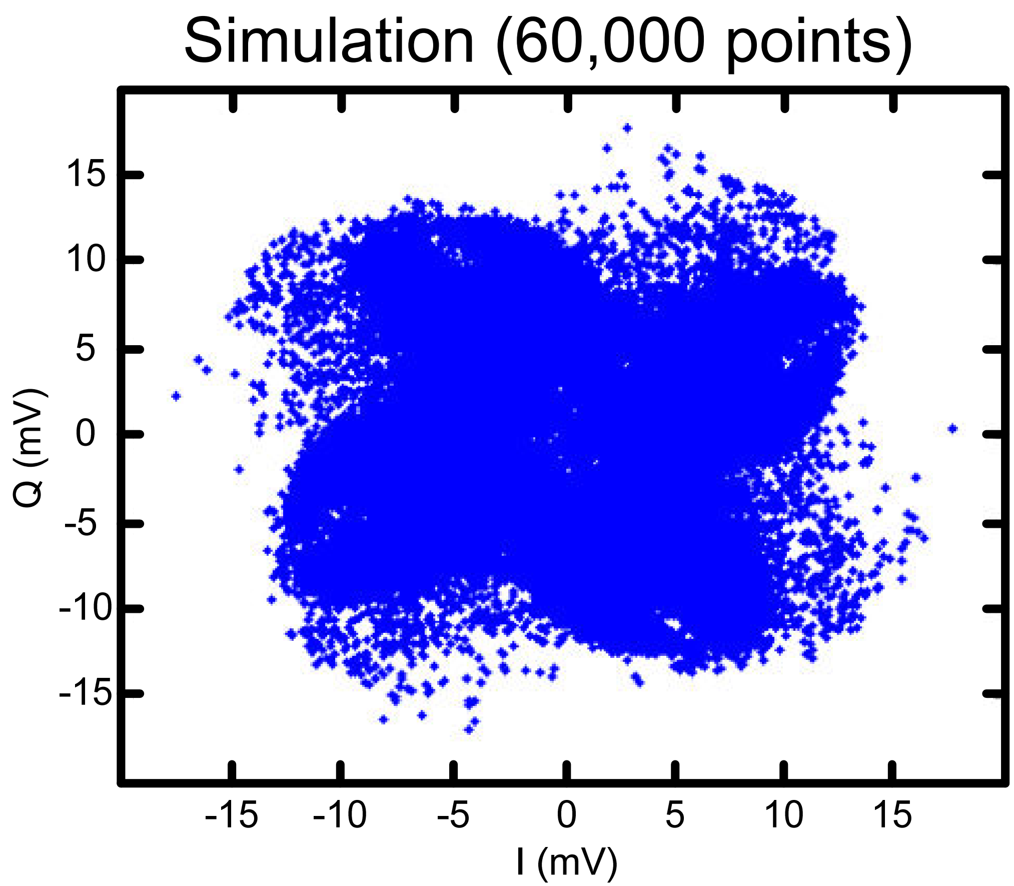
- For a total number of N switches on the reflectors, 2^N configurations exist. In our design N=90→2^{90}~10^{27}
- Redundancy can be used to generate a single constellation point with many different switching combinations.
- This will limit the ability of the undesired receiver to properly demodulate the signal.

Multiple-Beam Transmission



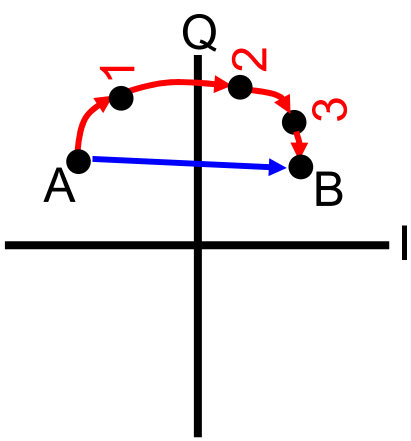
- Redundancy also helps us to transmit **independent data** to different directions at the same time using **a single transmitter** at its full rate.

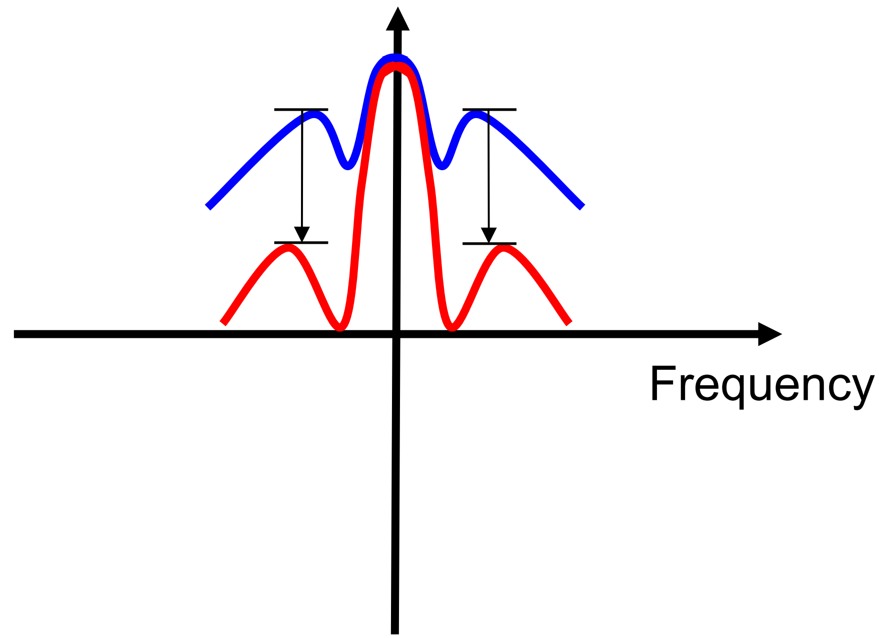
High-Resolution Coverage



- Based on the simulation, we can cover most of the signal constellation space with a high resolution.

Spectral Control





- Pulse shaping and out-of-band emission can be controlled by transition trajectory between two constellation points.
- Almost any arbitrary trajectory can be achieved by rendering the path using multiple points along the trajectory.

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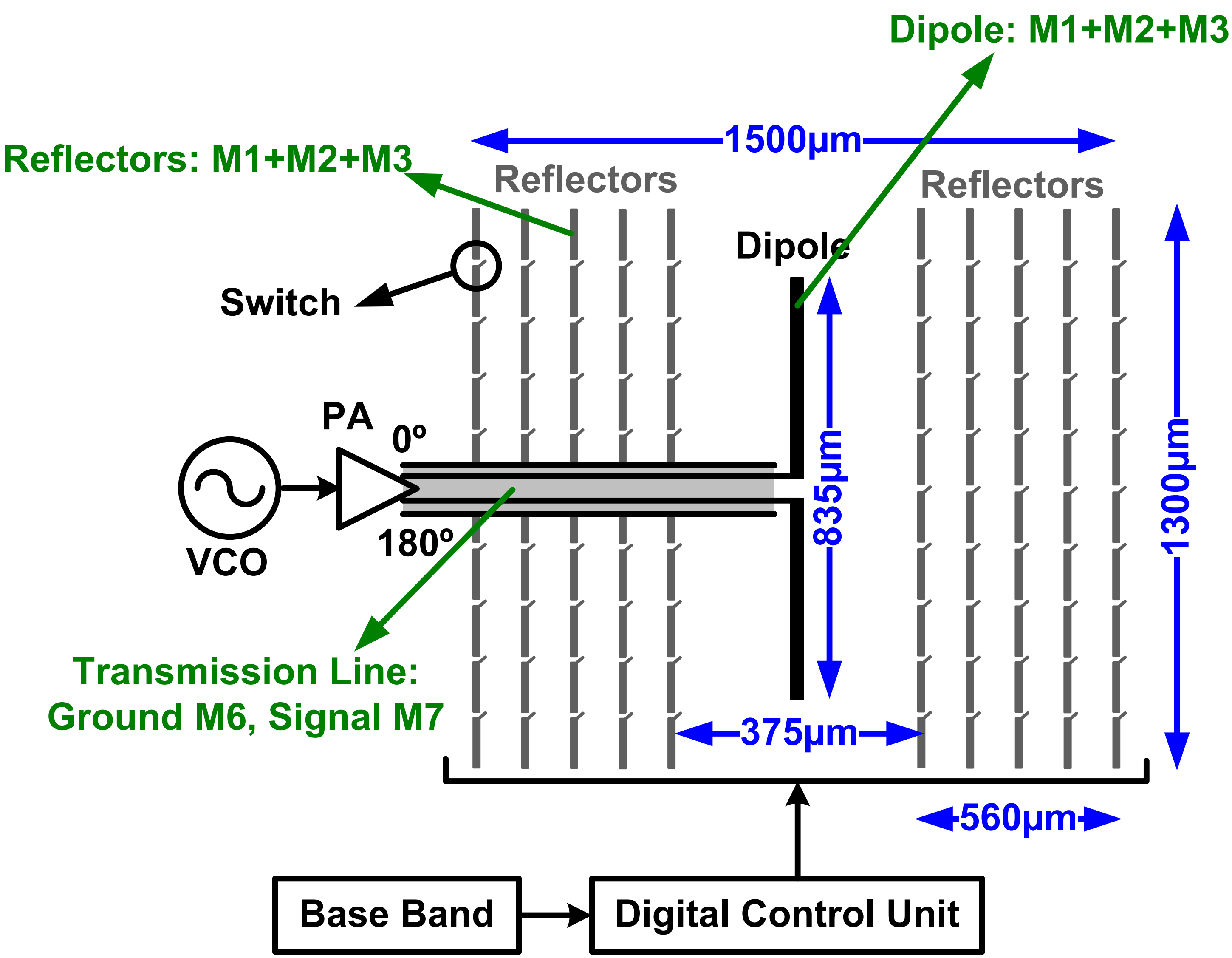
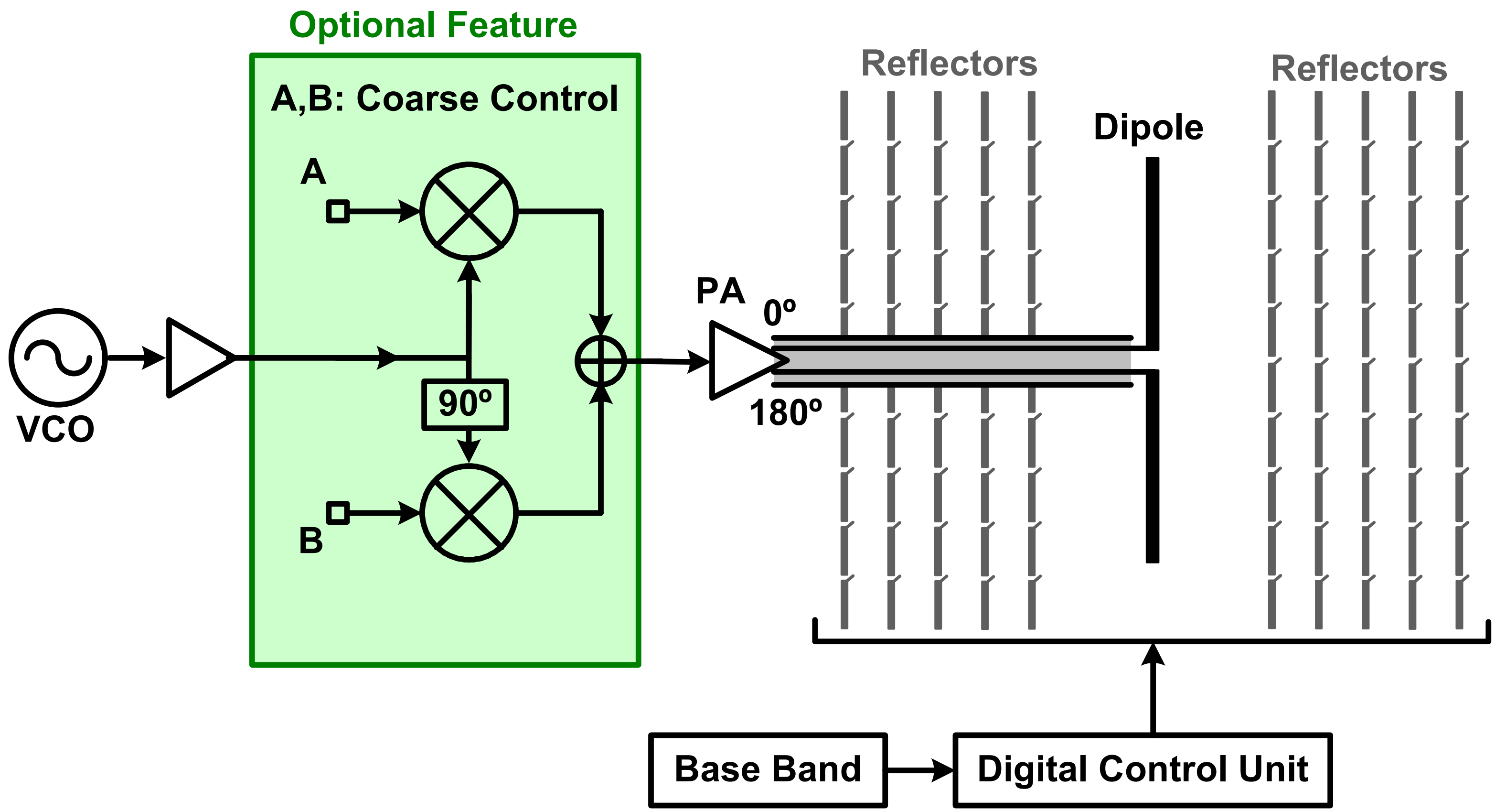
60GHz Transmitter with Antenna

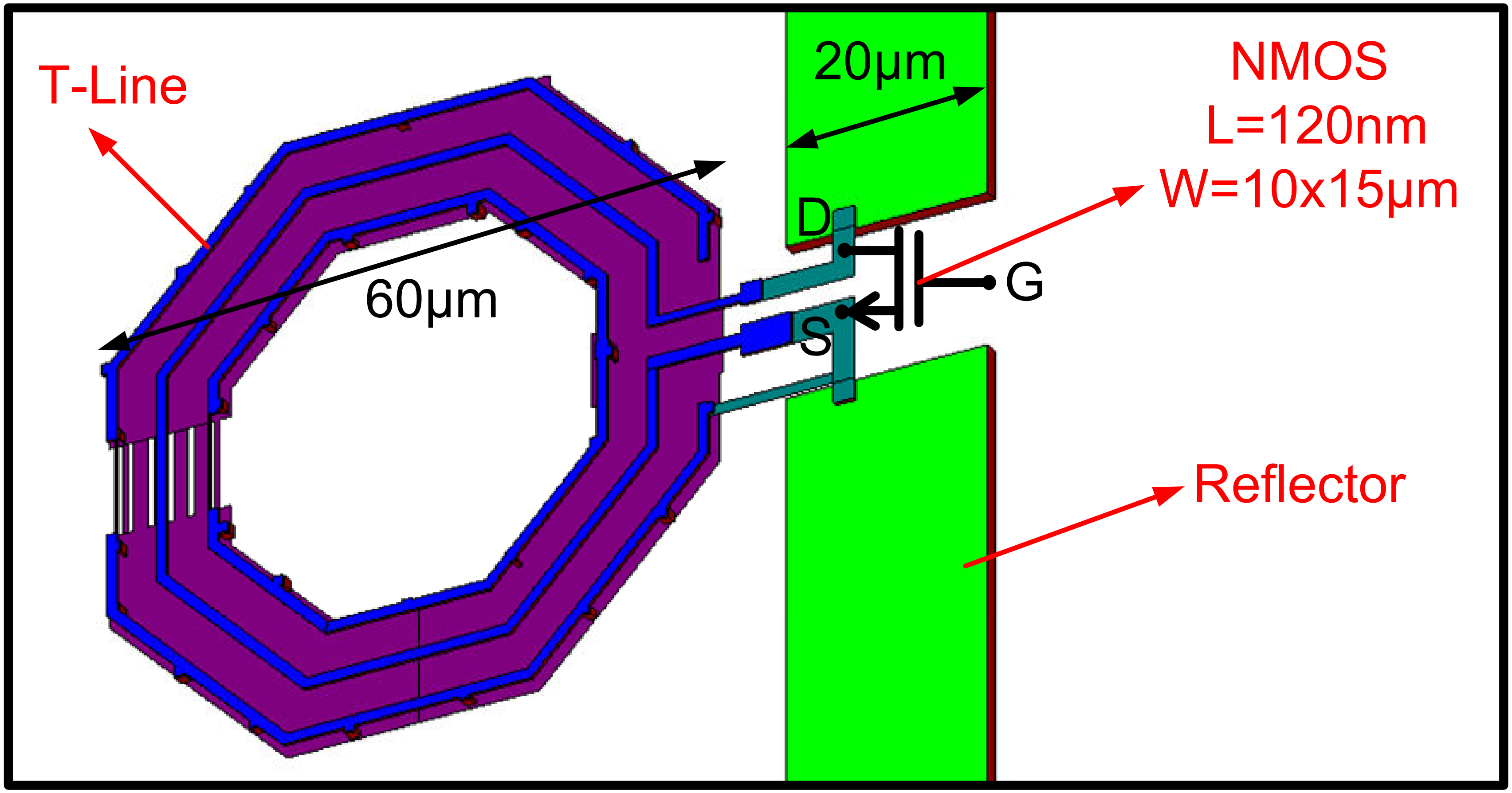


Optional Quadrant Selecting Unit



- An optional circuitry is designed to provide a coarse control on the phase of the modulated signal.
- This unit can be used to select a quadrant on the constellation diagram.

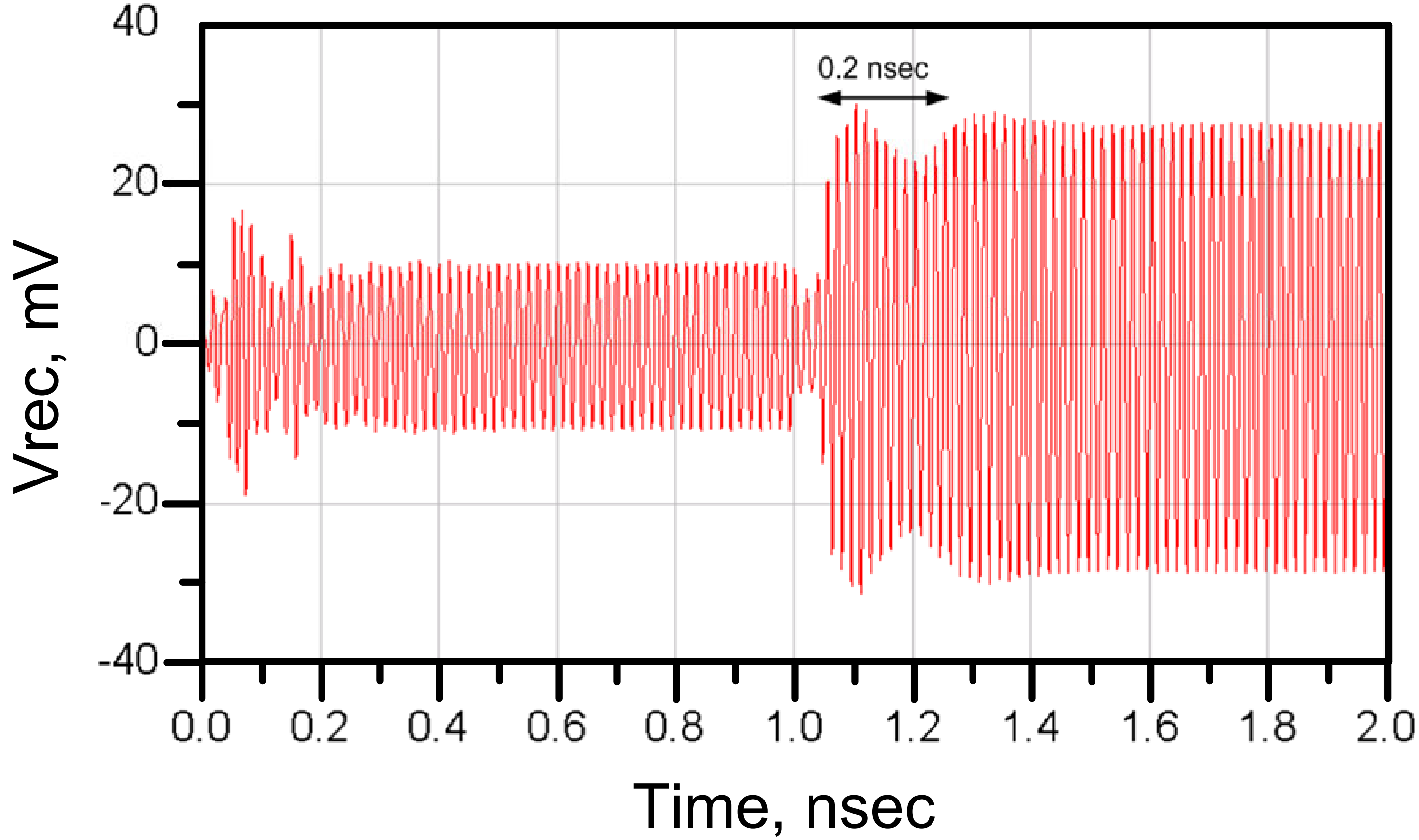
Switch and Reflector



- A circular shielded transmission line resonates out the switch capacitance at its open state.

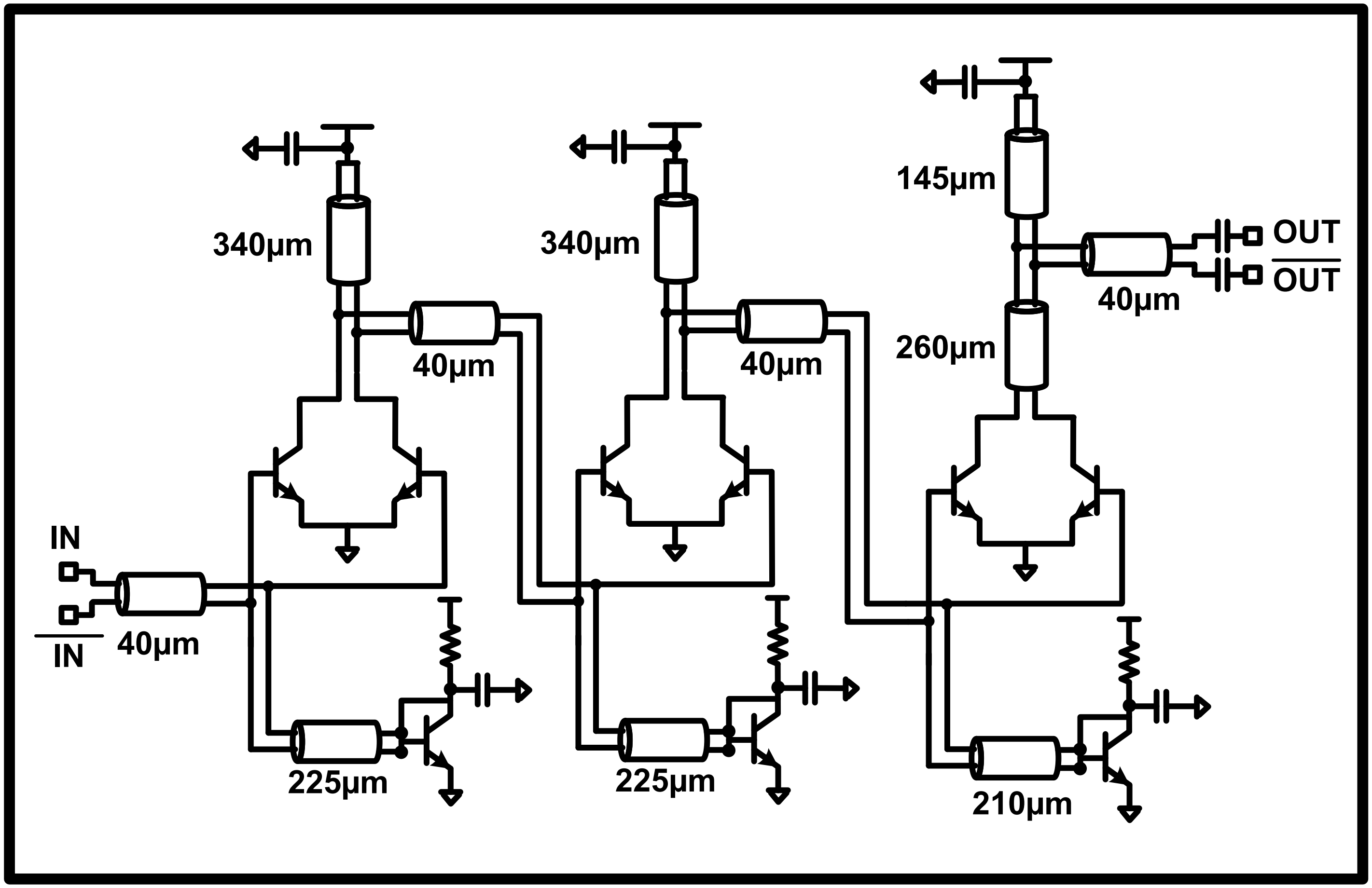
Reflectors Transient Response

(Simulation)



- For a carrier frequency of 60GHz the far-field adopts to the new switch combination in less than 200ps (ideal switch).
- Effectively, the transient response is limited by the switch itself.

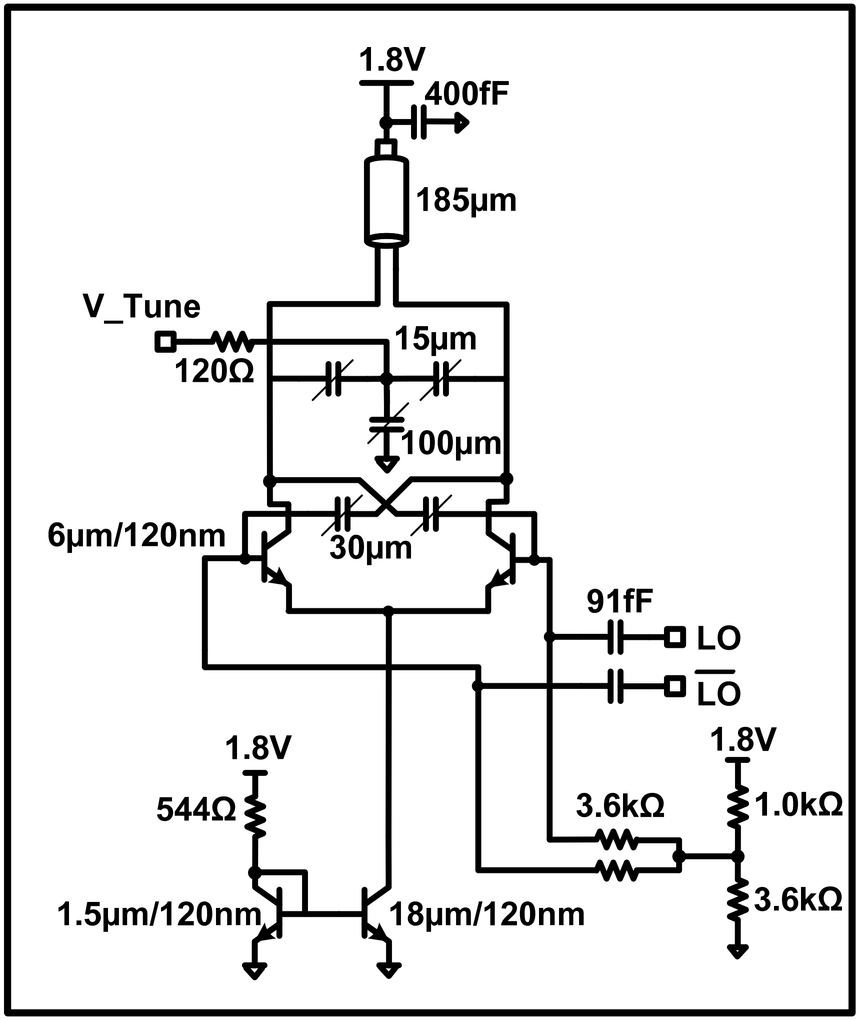
V-Band Amplifier



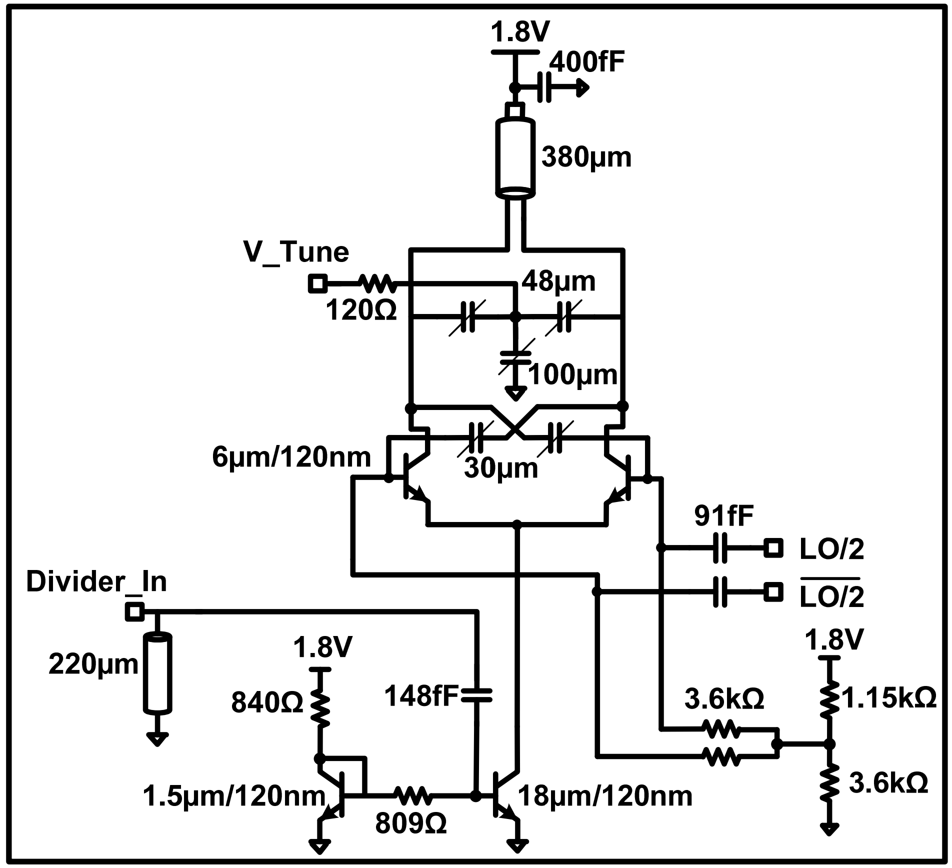
- A 3-stage amplifier drives the on-chip antenna.
- Coupled-wire transmission lines and stub tuning are used for matching purposes.

60GHz VCO and Divider

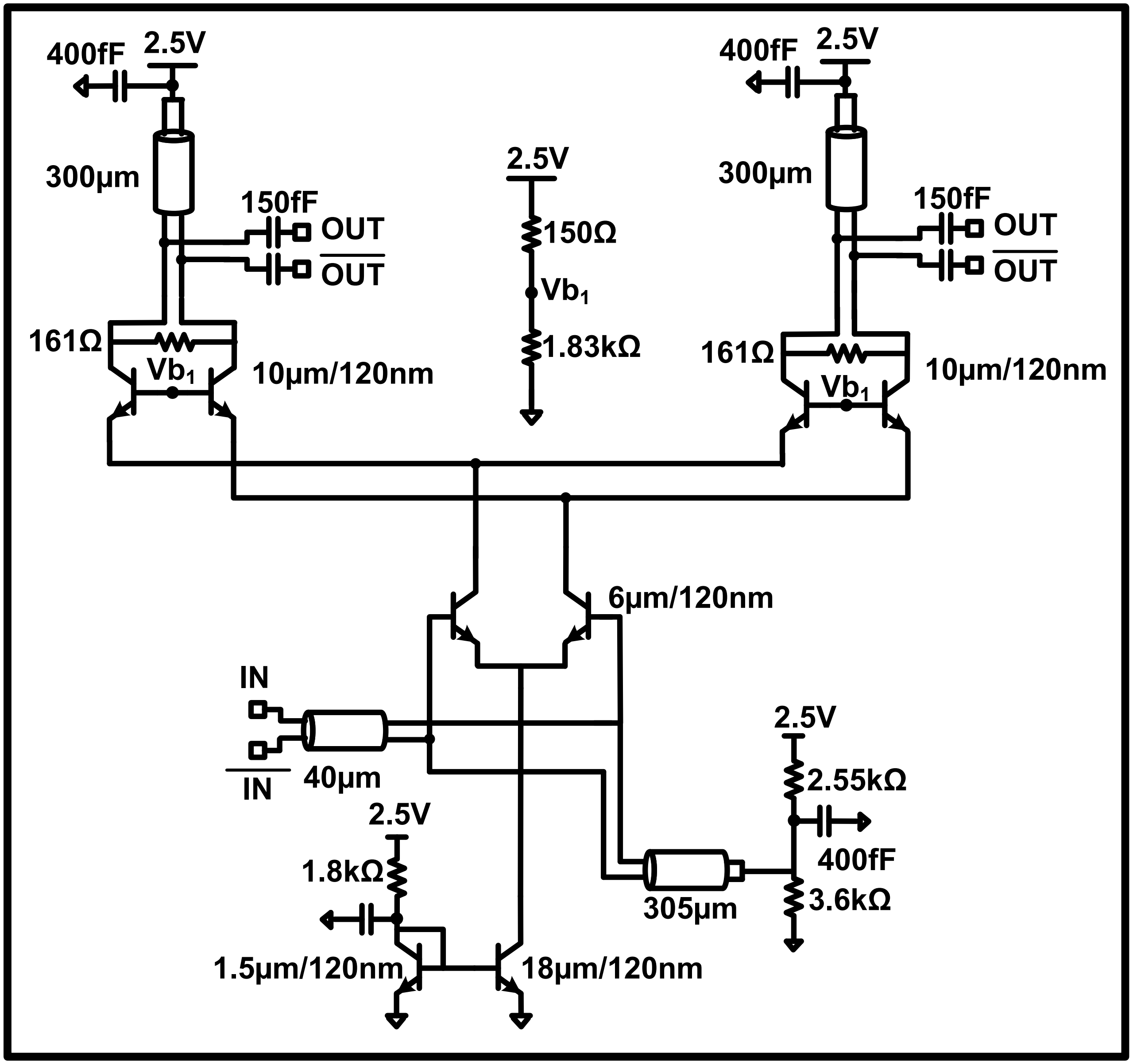
V-band VCO



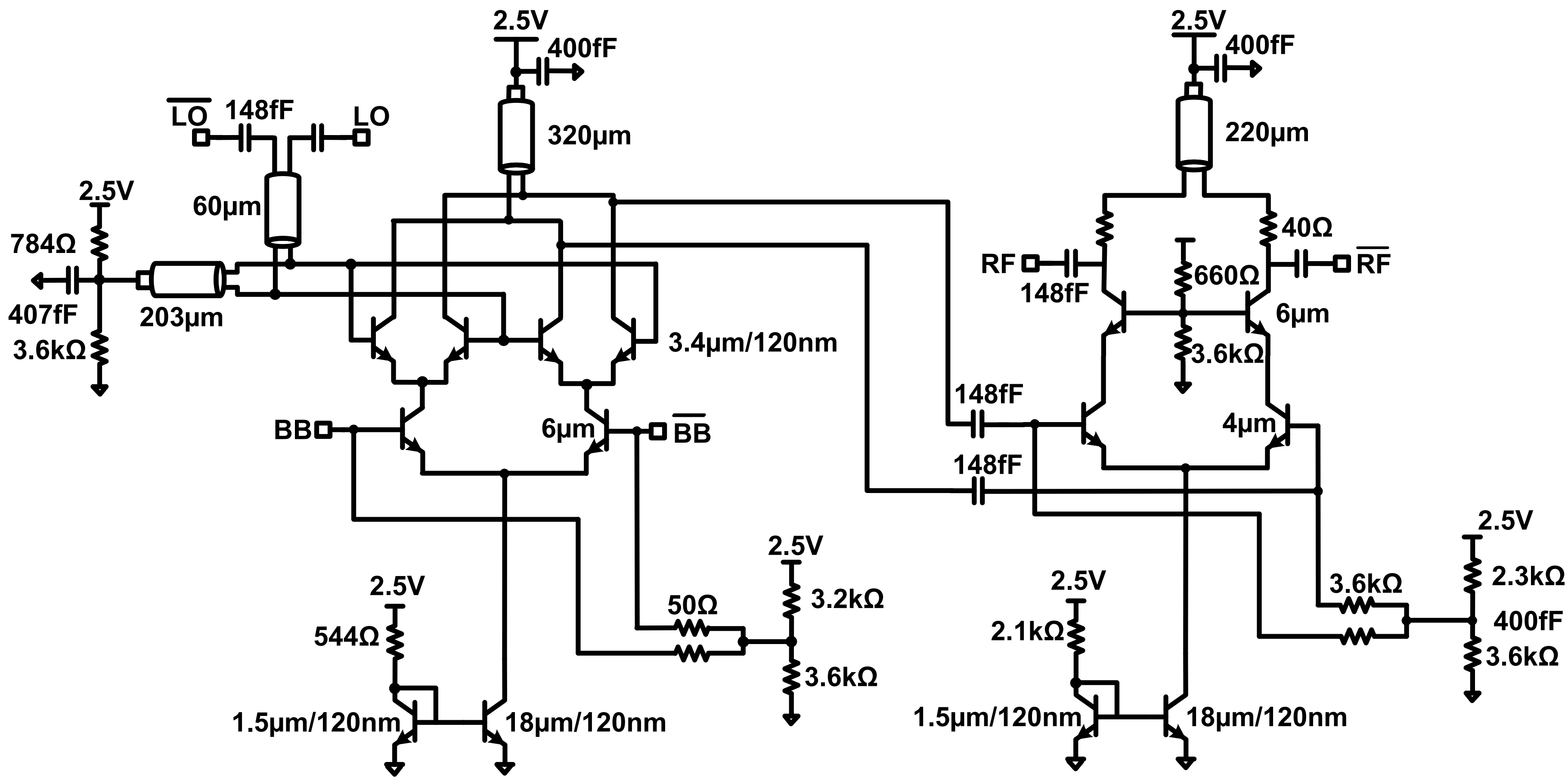
Injection-locked Divider



LO Signal Distribution



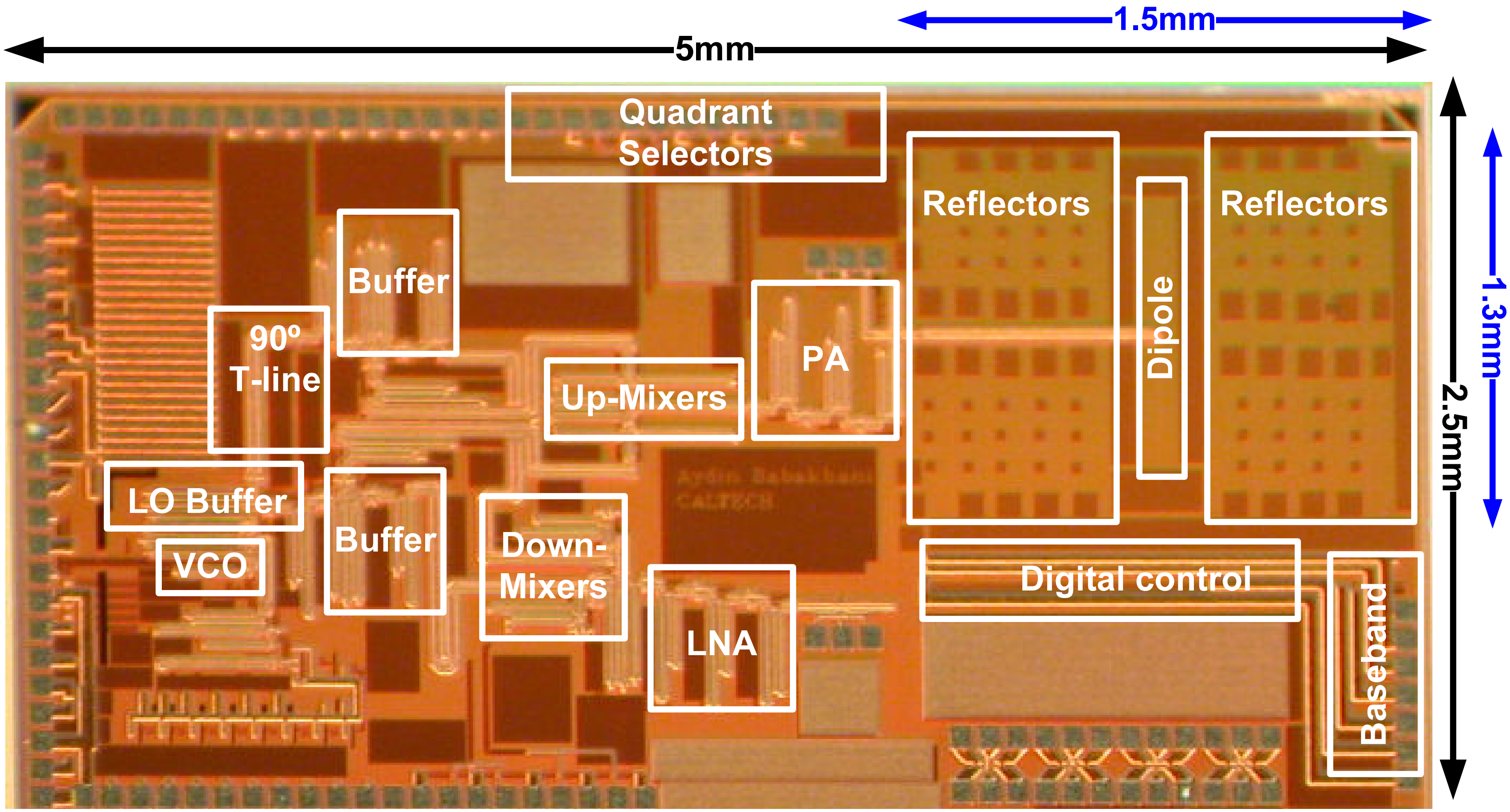
Up-Converter Mixer (Optional Feature)



Up-Converter Mixer

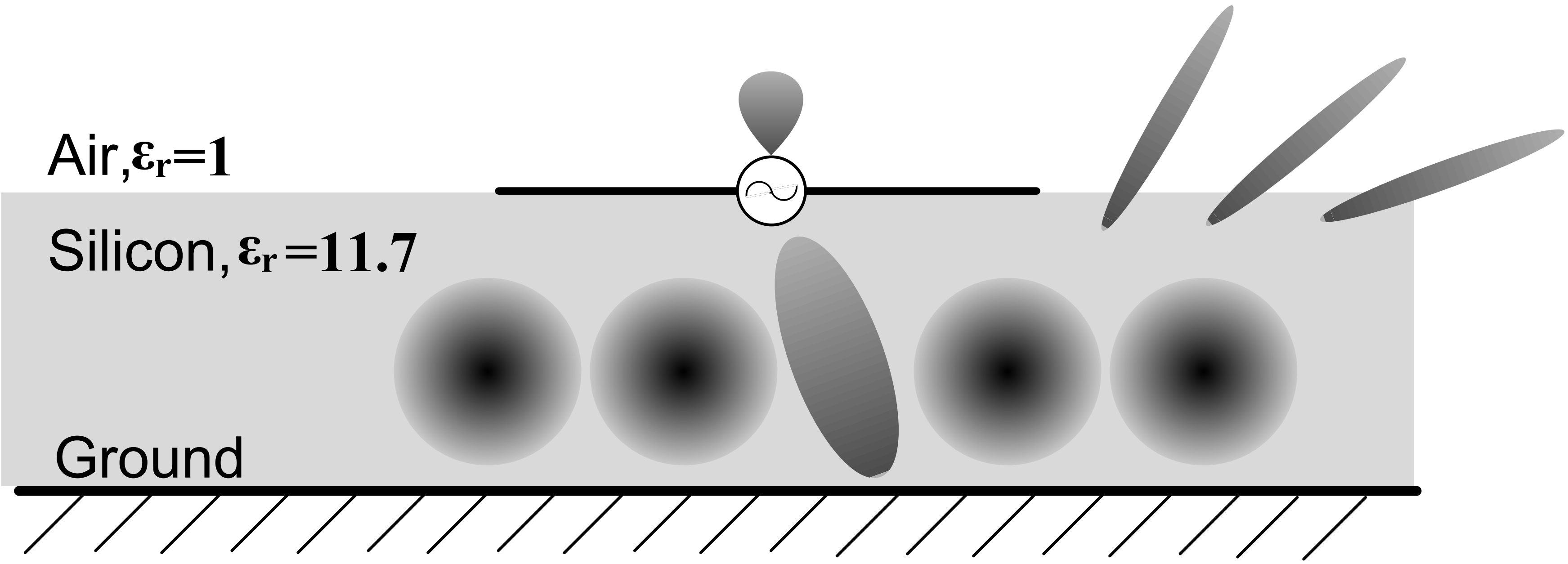
Buffer

Chip Micrograph



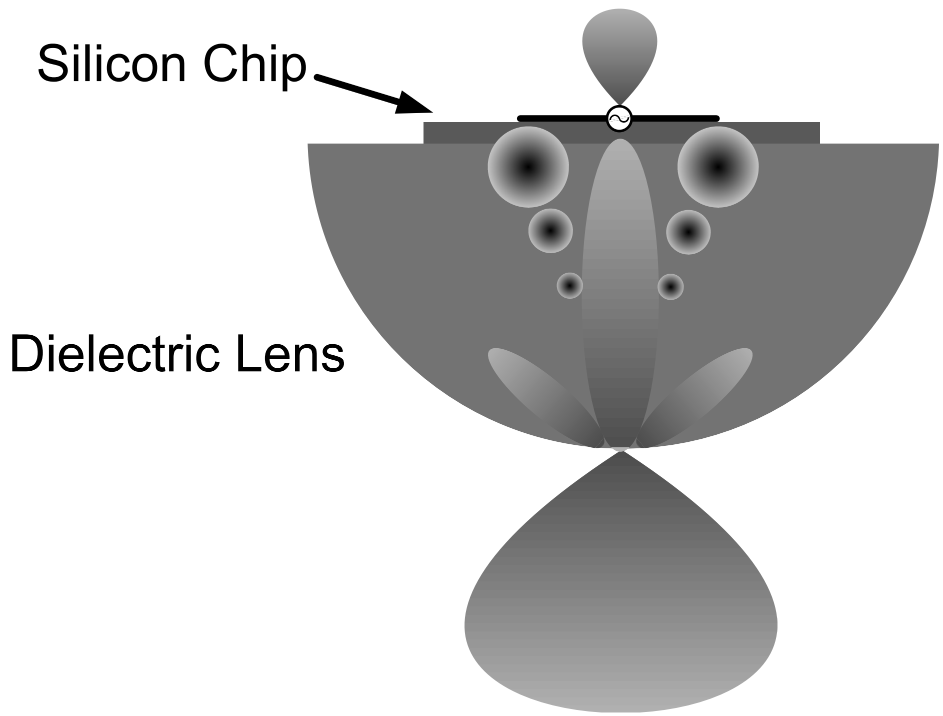
- The chip includes the on-chip antenna, reflectors, digital control unit, transmitter, receiver, and LO generation blocks.
- Chip is implemented in a 130nm SiGe BiCMOS process.

Substrate Modes



- Due to the silicon's high dielectric constant (11.7), most of the radiated power (95%) is coupled to the silicon instead of air.
- A planar substrate behaves as a waveguide and couples the power to the substrate modes.

Dielectric Lens



- To minimize the power lost due to the substrate modes, a hemispherical un-doped silicon lens with a diameter of 25-mm is attached to the back-side of the substrate.
- This silicon lens converts the substrate modes to useful radiated modes.

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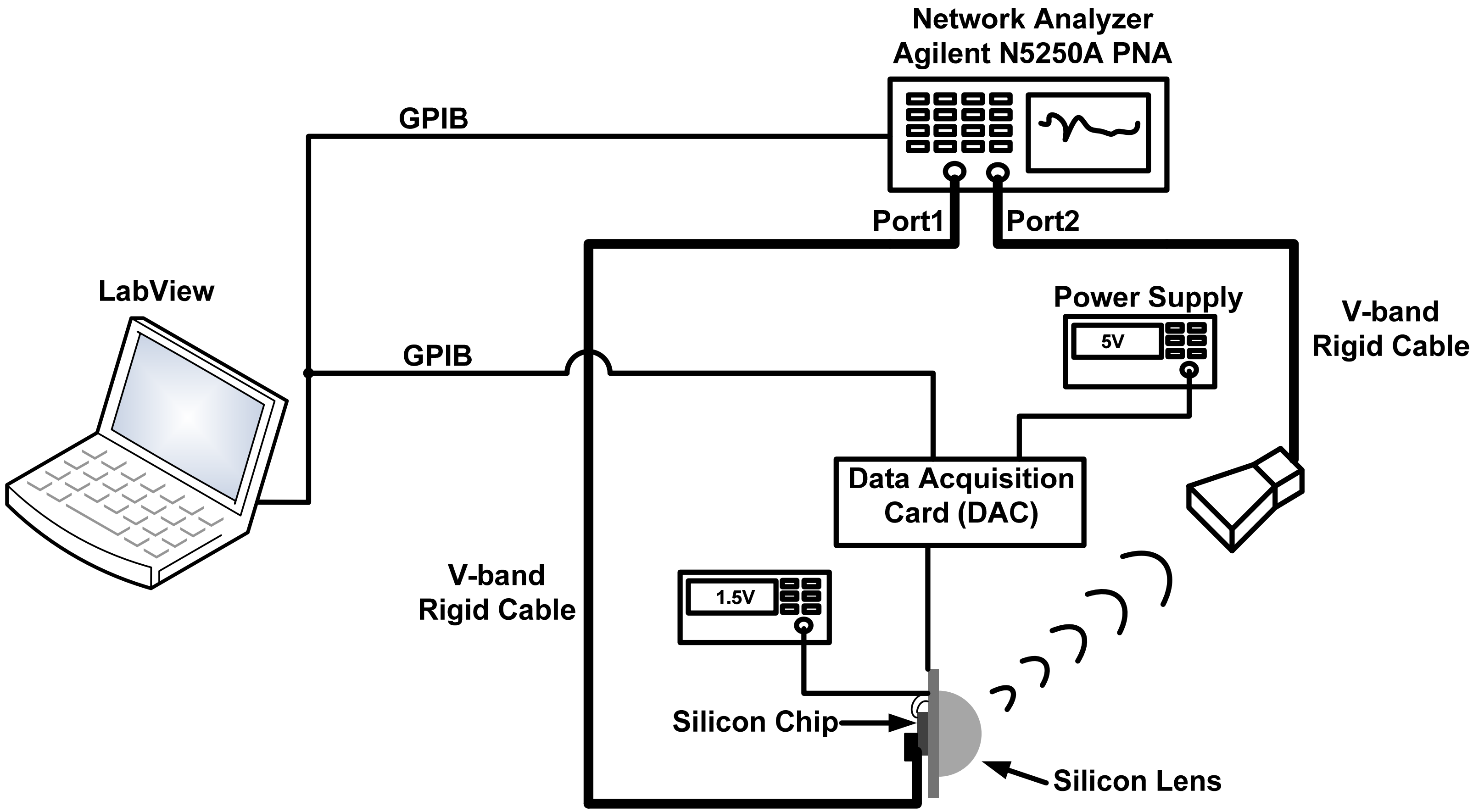
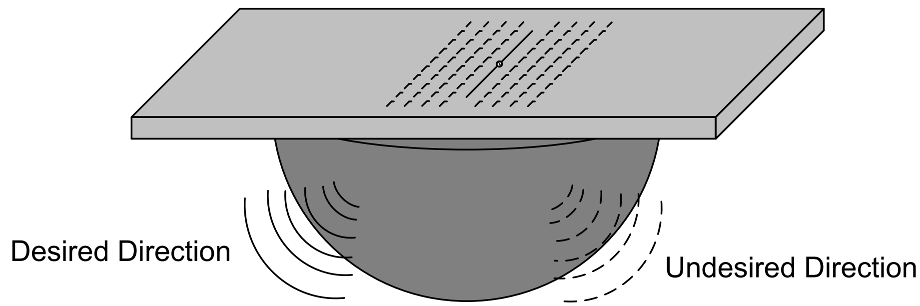
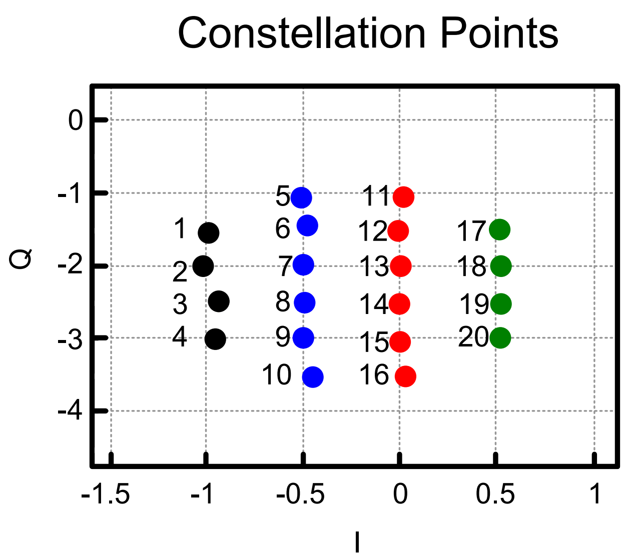
Measurement Setup

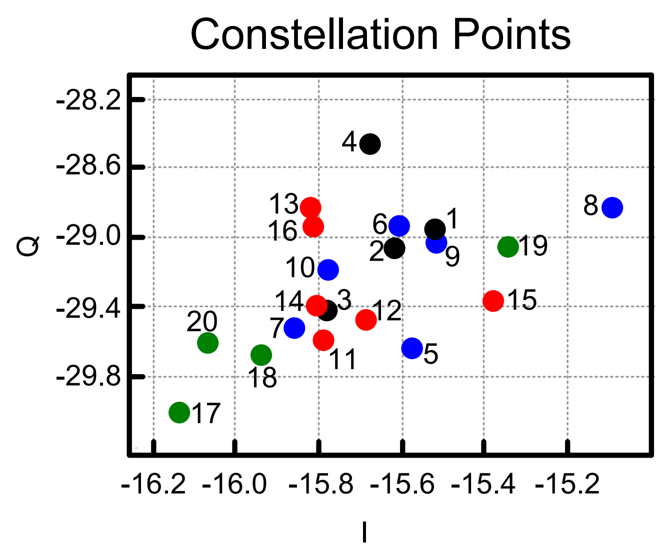


- A Lab-View program sends the base-band data to the transmitter through a data acquisition card and at a same time measures the changes in the phase and amplitude of S_{21}.

Measured Constellation Points

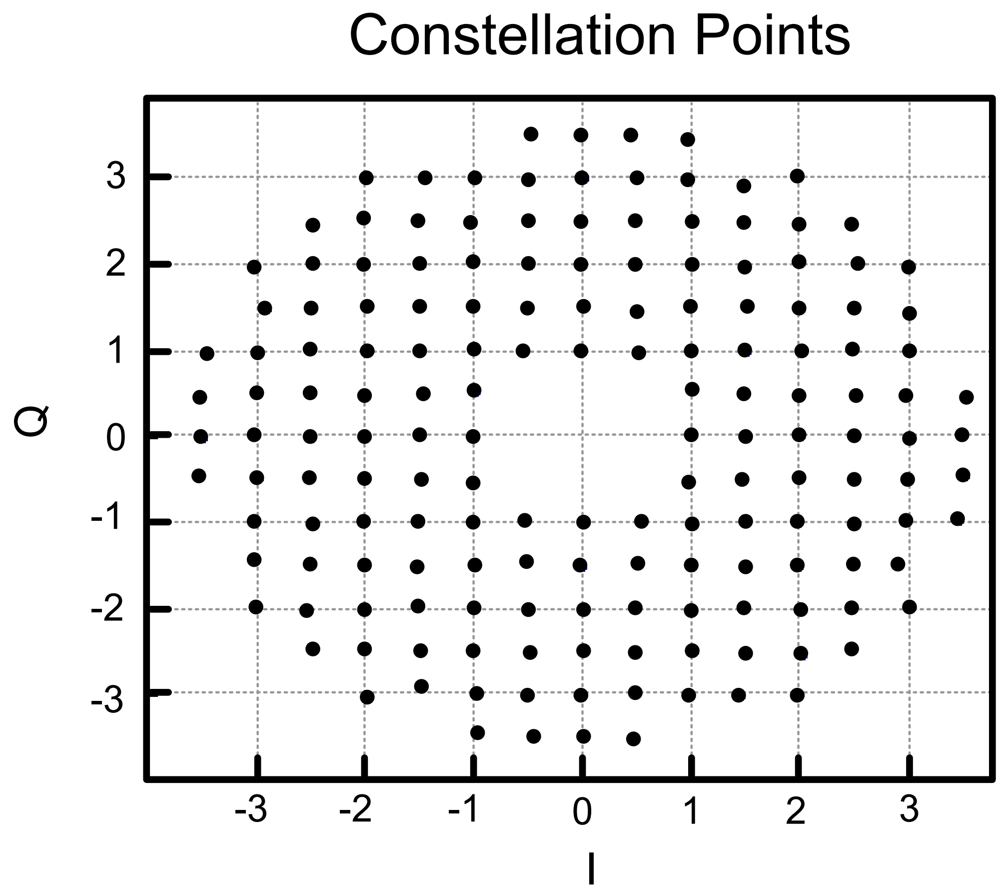






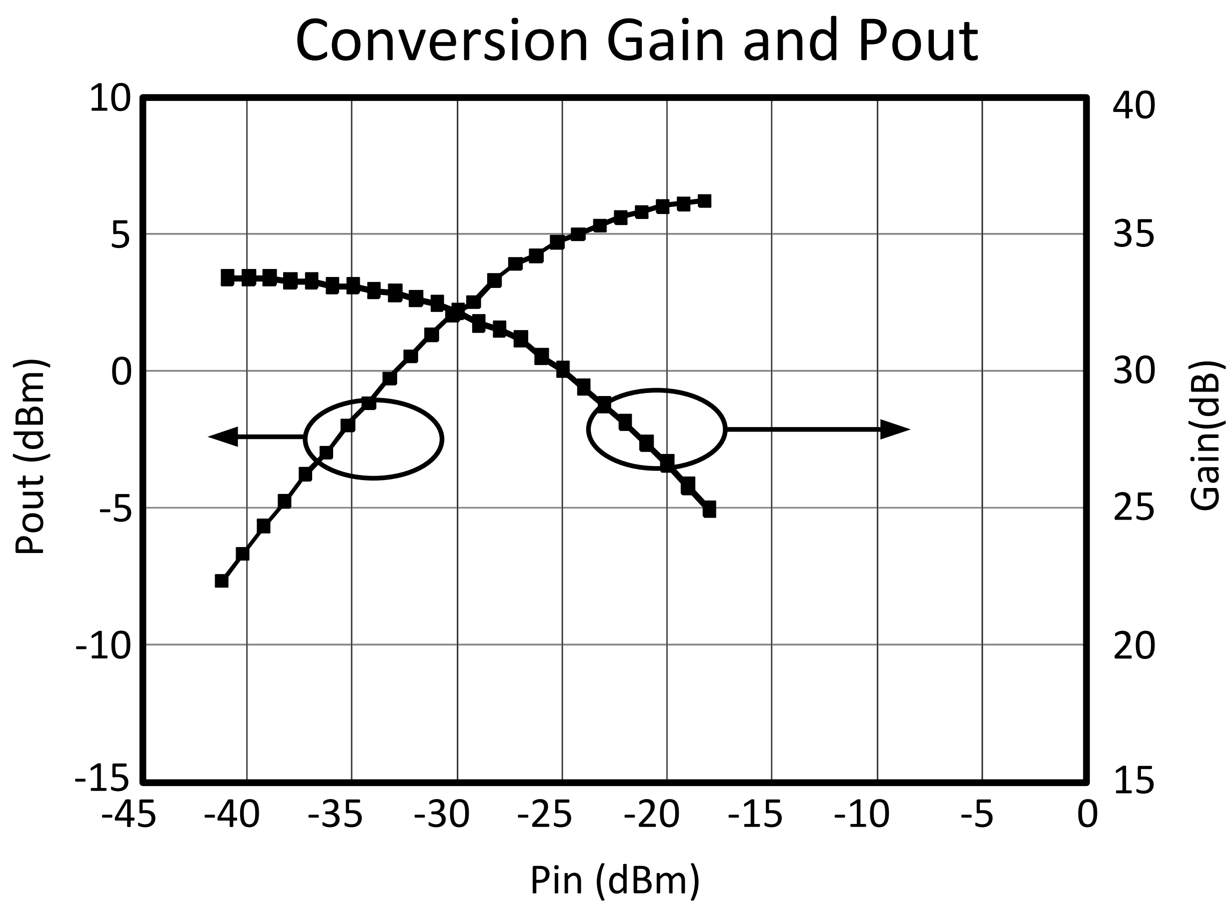
- In this measurement only the reflector switching is used to generate the modulated points.

Four-Quadrant Constellation Points



- To cover the four quadrants, the optional coarse control quadrant-selecting unit can be used.

Transmitter Gain and Power



- Measured gain of more than 33dB
- Measured output power of about +7dBm

Circuit Performance

Transmitter performance	
Technology	130nm SiGe BiCMOS
Amplifier output power	+7dBm
Transmitter small-signal gain	33dB
Transmitter saturated gain	25dB
VCO tuning range	2.5GHz
VCO phase noise	-100dBc at 10MHz offset

Conclusions

- **Signal Modulation using Antenna Reflector Switching (SMARS)** is introduced.
- This technique is capable of transmitting information to a desired direction while preventing receivers in undesired directions to properly decode the signal.
- Redundancy can be used to transmit **independent information to multiple directions** at a same time using a **single transmitter**.
- The whole switching reflectors including the antenna can be used as a single element in a phased array system. In this case, the switching combinations determine the **information beam-width** and the desired direction while the phased-array technique can be used to adjust the **radiation pattern beam-width** and steer the array pattern.

Acknowledgement

- Yu-Jiu Wang of Caltech for assistance in designing the digital blocks
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- Software Assistance: Cadence, Agilent Technologies, Zeland, Ansoft and Integrated Engineering Software

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